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LCA FOR ENERGY SYSTEMS AND FOOD PRODUCTS

# Effect of different allocation methods on LCA results of products from wild-caught fish and on the use of such results

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**Abstract**
*Purpose* The purpose of this study has been to investigate the effect of different allocation methods on life cycle assessment (LCA) results of products derived from line-caught cod and the consequences of applying these methods considering the main aims of this case study. These aims were for internal improvement work and communication of results to the market.
*Methods* Standard LCA methodology was applied. Mass allocation, economic allocation, a novel hybrid allocation and gross energy content allocation have been tested on a case study, and the results are discussed. In the case study, allocation problems in the studied case arose in the fishing and processing stages. Avoidance of allocation by splitting of processes, biological causality and system expansion or the avoided product approach was deemed to be not feasible.
*Results and discussion* Economic allocation gave a much larger spread of impacts between the different products than mass allocation, especially for processing residue, due to large price differences. Hybrid allocation gave impacts in between mass and economic allocation because the set factors give a higher value for products that are for human consumption. Energy allocation gave results close to mass allocation because the energy content is quite similar in different species and products. Economic allocation is sensitive to price changes, the others are not. When used for evaluating environmental performance improvement measures that change the relative yields for human consumption and other purposes, the different methods used reflected very different results. When used in communication to the market, the different allocation methods yield results that could lead to different behaviours by market actors.
*Conclusions* The different allocation methods gave very different results for the studied products; hence in order to achieve comparability between products, the same method must be used in all the cases. Different allocation methods might be appropriate for different purposes. For external communication to the market, mass allocation might be the preferred method in most cases. For internal improvement work, both economic and mass allocation could be used, but economic allocation might be the best alternative. The comparability of LCA results of products from wild-caught fish is limited, due to the lack of an agreed standard method. It is recommended to consider the different applications of the results when developing such a method. Different purposes might require different methodological choices, e.g. allocation methodology.

**Keywords** Allocation · Fish · Cod · LCA · Case · Standard · Method

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## 1 Introduction

Life cycle assessment (LCA) methodology is one of the main methodologies employed in the study of the environmental impacts of fish products. The methodology is standardised through ISO standards 14040 (2006) and 14044 (2006), but many methodological issues are left open, albeit with recommendations, for the LCA practitioner. Examples of such choices are goal and scope, system borders, allocation method, functional unit and impact categories.

The result of the lack of sufficiently standardised methodology is that results from different studies are difficult to compare. Hence, in cases where comparability is an important goal, there is a need to investigate the effect of the above-mentioned methodological choices on the results from LCA studies.

Allocation is one of the main methodological choices that potentially has a high effect on LCA results. Products from capture fisheries have often gone through a long value chain before being consumed. Some of the steps in the value chain are multiple output processes. In these steps, the environmental burden must be distributed among the outputs. Ayer et al. (2007) reviewed the allocation methodology used in fish product LCA and identified four main life cycle stages where allocation is often used. For wild fish, the fishing and processing stages are appropriate.

ISO Guidelines recommend the following hierarchy for decisions on allocation: 1. System expansion. 2. Allocation based on physical and biological causality (that reflects how inputs and outputs are changed by quantitative changes in the products and the functions rendered by the system). 3. Where such causality cannot be determined, allocation shall be based on other relationships between output and input, e.g. mass, volume or economical value.

The simplest way of avoiding allocation is to include all products in the same functional unit, a so-called global functional unit (GFU). This is possible in both the processing step and fishing stage, as has been done by Hospido and Tyedmers (2005) and Hospido et al. (2006). However, the usefulness of this approach depends on the goal and scope of the study. If the goal of the study is to give information on the environmental performance of individual seafood products, this approach is not feasible because such results will not be available. If the purpose of the study is to identify options for the improvement of environmental performance in the fishing stage, the approach could be useful. However, the use of a GFU would be confusing if the different species caught are processed in different locations using different processes. It would also be difficult to use a GFU as a basis for identifying options for improvement later in the value chain. Another way of avoiding allocation is specified by the ISO standard. If the involved processes could be split according to the resulting products, allocation could be avoided. Such splitting is not possible in the fishing stage because the processes are not separated in space and time. The same can be said for the processing stage, except for the second processing stage where deep-fried products are produced.

A third option suggested in the ISO standard is the avoided product approach described by Ayer et al. (2007), Thrane (2005, 2006). Thrane calculated the impact of flatfish products by calculating the impact of separate fisheries of all seven species by-products and subtracting the impacts of each of these species from the total impact of flatfish fishery. Thrane further avoided allocation in the processing step by assuming that by-products replaced existing products on the markets (e.g. fish mince used in fish balls assumed to replace pork meat) and by subtracting the environmental impact of producing these replaced products. This approach can be used if the data on single-species fisheries of the same stock are available, which was not the case in this study. It could be used in the processing stage if one predominant substitute product could be identified for each product. Such products could not be identified in the case used as basis for this study. The second best option, according to ISO, is allocation based on physical or biological causality. Schau and Fet (2008) argues that biological causality should be equivalent to physical causality. An example of biological causality, given by Schau and Fet (2008), is the way emissions of methane from ruminants depend on the feed content. Another example is the allocation of feed to milk and meat production done by Cederberg and Mattsson (2000). No biological or physical causality could be identified in this case. The third option, allocation based on other relationships between output and input, is the most frequently used option in published fish studies. Ayer et al. (2007) and Schau and Fet (2008) have shown that economic allocation and mass allocation are the most commonly applied allocation methods in the studies of fish products.

Ziegler (2006) used economic allocation in several processes both for frozen cod fillets and Norway lobster. The main reason was the great differences in value between processing outputs and between fish species, which meant that the involved fishermen and processors would act to increase the most valuable outputs. Several studies have used mass allocation, including Eyolfsdottir et al. (2003), Hospido and Tyedmers (2005), Vázquez-Rowe et al. (2010) and Winther et al. (2009). Eyjollfsdottir et al. (2003) studied trawled cod. They found that the difference in the fishing stage between the cods' economic value and share of captured mass was so small that these two allocation methods would give very similar results. Given the dependency of prices that may vary widely because of decreasing catch quotas, the authors preferred mass allocation. Winther et al. (2009) did a generic study on a number of generic Norwegian seafood products, from farmed and wild-caught fish. They discussed allocation in detail and chose mass allocation because of the stability over time. They also argued that the method is more closely related to the function of fish and more directly linked to underlying physical realities such as mass and energy flows.

The study by Ayer et al. (2007) is a review of different co-product allocation methods in fish LCAs. The authors propose allocation based on gross energy content because it is more closely linked to these biophysical flows of materials and energy and bridges biophysical and economic considerations. Winther et al. (2009) describe gross energy

allocation as being counter-intuitive because the by-products from processing are higher in energy content and consequently should carry more environmental impact than the products for human consumption. A combination of two different allocation methods is also possible, e.g. mass and economic allocation. Such a combination could be called a hybrid allocation. One such hybrid method has been proposed by Ziegler (2008) and can be described as follows. The mass is multiplied with a set factor of:

- 1 for products going to human consumption
- 0.5 for products going to animal feed
- 0.25 for products going to incineration

What are the implications of using different allocation methods on the results, and what are the practical consequences when the results are applied for different purposes? A few studies show that the impacts are potentially great. Schau et al. (2009) found large variations in energy consumption in Norwegian fisheries of Atlantic cod depending on allocation method. The average using mass allocation was 0.35 kg fuel per kg fish caught but 0.5 kg fuel per kg fish caught using economic allocation. Thrane (2005) found large differences in the fuel consumption for cod fish (e.g. cod, haddock, saithe) fisheries, from 0.36 using system expansion, 0.47 using mass allocation and 0.86 using economic allocation. There appears to be a need for case studies that investigate the impact of methodological choices on products existing in the market. In this article, data from one case study described by Svanes et al. (2011) on products sourced from cod caught by the autoline fishing method in Norwegian territorial waters is presented to shed light on the discussion on allocation methodology. The aim of the case study was twofold: (1) guide the involved companies in enhancing the products' environmental performance and (2) communicate the results of the environmental performance towards customers enabling them to make informed purchasing decisions. The discussion of allocation methods must be seen in light of these purposes. It is not the intention of this article to arrive at general conclusions about the choice of allocation methodology in fish LCAs. However, this study is intended to support and contribute to a standardisation of calculation methods of environmental impact of fish products. One such process is the development of a PCR for seafood currently taking place in Norway, in the form of a national standard.

## 2 Goal, scope and method

### 2.1 Aim

The aim of this study has been to explore the effect of different allocation methods in LCA results from a case study of products from wild-caught cod. Another important aim has been to explore the effects of the allocation methods on the intended aims of the case study. It is hoped that this study could provide input for the development of a standard method (or methods) or guidelines for calculating environmental impacts of fish products through LCA methodology. Such a method could give comparability of environmental performance results for fish products. When used by consumers, purchasers and other interested parties, it could give an incentive towards reducing the overall environmental impacts of seafood products. It could also help actors in the value chain to improve their environmental performance through targeted improvement measures. Another potential area is for governments in their effort to device efficient fishery policies.

### 2.2 Description of case study

The case studied is a LCA of products derived from cod caught by fishing vessels in the North Sea and the Bering Sea using an automated longline ("autoline") fishing method. The main multiple output stages are the fishing stage and the processing stage. In the fishing stage, 15 species are caught; of these, eight species are caught in great amounts. The vessels go on six trips a year, each trip lasting approximately 6 weeks. Cod is often the target species, but sometimes other species such as tusk, ling or haddock is targeted. This is due to the demand in the market and quotas and availability of fish.

The cod heads and guts are removed and discarded. Roe and liver are removed and frozen separately at times of the year when the quality is sufficiently high. The gutted and beheaded fish are sorted according to species and size and frozen very soon after being hauled aboard.

The fish is brought ashore and thawed in the processing plant. Processing gives five main outputs: loins (back piece of the fish, highest quality part), tail and belly part, mince, block, bones and skin. Skin, fins, bones and some other parts not fit for human consumption is used for animal feed. The products derived from these main outputs vary a lot in economical value, approximately by a factor of 100 from the lowest to the highest value product. Loins are transported chilled. They are transported in EPS boxes with ice to customers, mostly abroad. The other products are frozen after processing. Wetpack and individually quick frozen (IQF) are the main products from tail and belly pieces, both sold in 400 g packages. Part of the mince and block is mixed with other ingredients such as vegetable oils and flour and deep fried. The product analysed in this study is fish burger in 5 kg packages, which is sold to professional users such as school kitchens. The processing residue (skin, bones, fins, etc.) is frozen in big blocks and sold for use in feed to fur animals. The reference market for the loins

products is UK, Sweden for Wetpack, IQF and fish burger and Norway for the residue.

### 2.3 Context

This study is part of the research project “From Seafloor to Consumer”. The aim of this study was to document the environmental efficiency of the value chain from the capture of the fish to consumers’ table and to calculate the impact of reduction measures along the value chain. The results of the documentation of environmental efficiency could be used in communication with consumers, procurers and other market players.

### 2.4 Functional unit

The different functional units are presented in Table 1.

### 2.5 Description of system

Fishing, processing, packaging, transport and storage by Domstein and wholesaler and shops are included. Equipment use is included, as are fishing lines. A lifetime of 3 years for main lines and other equipment is assumed. The whole-life cycle of the diesel and other resources used is also included. Infrastructure was not included because calculations showed that the impact was insignificant (<1% of total impacts).

### 2.6 Method

The study was carried out using LCA methodology based on the ISO standards 14040 (2006) and 14044 (2006). The impact assessment method used for most impact categories was CML 2 baseline 2000, V2.04. For cumulative energy demand, the method used was CML 1992 V2.05 and Cumulative Energy Demand V1.05 by Ecoinvent. The following environmental impact categories were included in this study: global warming potential, acidification potential, eutrophication potential, photochemical ozone creation potential and cumulative primary energy demand. The SimaPro 7.1.6 software was used together with the Ecoinvent 1.3/2.0 database in order to carry out the analyses performed.

## 3 Results

The main results of this study are displayed in Tables 2 and 3. The most striking features of the results are the variation in magnitude between the products, even though they are sourced from the same raw material, and the variation for the same product using different allocation methodologies. In general, the results from the impacts were, in decreasing order: loins product>IQF>wetpack>cod burger>animal feed by-product. For eutrophication, the order was slightly different: loins product>cod burger>IQF>wetpack>animal feed by-product. The difference in values for each of the products using different allocation methods is visualized in Fig. 1, using GWP as an example. The reason for using GWP is that there is in the general public a larger focus on this environmental impact, and the fact that a similar pattern can be seen using all the other impact categories. From Fig. 1, it is clear that the largest difference between products can be seen when using economic allocation. The method giving the smallest variation between products is mass allocation. The energy allocation results are almost similar to those of mass allocation. Hybrid allocation represents an intermediate case between mass and economic allocation.

The effect on the animal feed by-product is particularly large, the result for mass allocation being 8.5 higher than for mass allocation. For the other products, this ratio is 1.7 (loins product), 1.6 (wetpack and IQF) and 1 (cod burger).

The observed differences may have several causes. The system borders are not identical for the products. Cod burger is followed all the way to the consumer, IQF and wetpack to the point of sale in retail, whereas the system for the loins product stops at the regional distribution centre. The system for the processing residue does not include reprocessing into animal feed. Transport distances are also very different. The transport to UK is much longer than the others. This is largely due to the fact that the direct transport from Western Norway to the processing plant in

**Table 1** Functional unit

| Functional unit | Source | Sales unit | State | System border ends at: |
|---|---|---|---|---|
| Wetpack, 1 kg | Belly and tail pieces | 400 g packages | Frozen | Retail in Sweden |
| IQF, 1 kg | Belly and tail pieces | 400 g packages | Frozen | Retail in Sweden |
| Fish burger, 1 kg | Mince, block and plant-derived ingredients | 5 kg package | Frozen | Institutional buyer in Sweden |
| Loins product, 1 kg | Back piece (loin) | 2 kg package | Chilled | Regional distribution centre in the UK |
| Processing residue, 1 kg | Skin, bones and other residue from processing | Large blocks | Frozen | Buyer in Oslo, Norway |

**Table 2** Environmental impact of products from back piece (loins) and belly + loin parts (wetpack and IQF)

| | | Loins product | | | | Wetpack | | | | IQF | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Economic | Mass | Hybrid | Energy | Economic | Mass | Hybrid | Energy | Economic | Mass | Hybrid | Energy |
| Global warming potentia | kg $CO_2$-eq | 7.6 | 4.4 | 4.8 | 4.5 | 3.6 | 2.2 | 2.6 | 2.4 | 3.7 | 2.3 | 2.7 | 2.5 |
| Ozone layer depletion | kg CFC-11-eq | 1.2E-05 | 5.0E-06 | 5.9E-06 | 5.4E-06 | 6.4E-06 | 3.3E-06 | 4.2E-06 | 3.7E-06 | 6.4-07 | 3.4E-06 | 4.2E-06 | 3.7E-06 |
| Photochemical oxydation | kg $C_2H_4$-eq | 0.01246 | 0.00573 | 0.00653 | 0.00611 | 0.00659 | 0.00367 | 0.00446 | 0.00402 | 0.00664 | 0.00372 | 0.00451 | 0.00407 |
| Acidification | kg $SO_2$-eq | 0.053 | 0.025 | 0.028 | 0.026 | 0.028 | 0.016 | 0.019 | 0.017 | 0.028 | 0.016 | 0.020 | 0.018 |
| Eutrophication | kg $PO_4$-eq | 0.00119 | 0.0058 | 0.0065 | 0.0061 | 0.0062 | 0.0035 | 0.0043 | 0.00039 | 0.0064 | 0.0037 | 0.0044 | 0.0040 |
| Primary energy demand | MJ | 112 | 68 | 73 | 70 | 58 | 39 | 44 | 41 | 61 | 42 | 48 | 44 |

the UK was not possible in this case. For processing residue, only the transport to Oslo is included. The other products are sent to Sweden, giving intermediate transport distances. The loins product is processed and packaged twice, the others only once. Loins are transported chilled, the other products frozen. Packaging is also very different. The weight of packaging per FU is high for the loins product, but very low for processing residue. The other products lie in-between.

The calculation of energy allocation is based on data on energy content of the fish species and between different parts of the fish Cod represents 35.7% of the catch weight and 36.9% of the gross chemical energy content of the catch. The energy content of the various parts of the cod was assumed to be very similar (based on information from the processor), hence allocation based on energy content was identical to mass allocation in the processing stage.

One important difference between economic allocation and the other methods is that prices are used in the calculation. The others use mass, set factors and energy content. From 2007 to 2008, the price of cod decreased in relation to the other caught species, and the price of the loins product fell substantially, whereas the prices decreased only marginally for the other products. The effect of price changes is illustrated in Table 4, again only for GWP. The effect for loins products is −16%, wetpack/IQF +6%, burger −6% and processing residue −6%.

Several products were awarded ecolabels during the project period. Ecolabelling not only incurred some extra costs for the fishing vessel operator, but also increased the market value for the products. This meant that the production company could take out a price premium for IQF and wetpack. The other products were not awarded KRAV certification. The increase in price gave a 5% higher GWP for the wetpack, using economic allocation.

Table 5 illustrates the environmental effect of one remediation measure, utilising the whole biomass of the caught fish rather than discarding guts and heads, which constitutes approximately 30% of the whole fish. The price that the guts and heads could fetch is unknown, so a low value is assumed (1% of the value of the total catch). The table show that utilisation of the whole fish is, for the fishing vessel operator, an attractive option using mass allocation, but makes little difference using economic allocation. For the buyer of the guts and heads, the opposite is true. Economic allocation would give a low GWP, which would be good for the buyer; mass allocation would be negative.

## 4 Discussion

Four different allocation methods have been tested, using results from one case study and considering the intended purposes for the results of that study.

**Table 3** Environmental impact of products from mince and block (cod burger) and processing residue (animal feed by-product)

| | | Cod burger | | | | Animal feed product | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Economic | Mass | Hybrid | Energy | Economic | Mass | Hybrid | Energy |
| Global warming potentia | kg $CO_2$-eq | 1.8 | 1.8 | 2.1 | 1.9 | 0.2 | 1.7 | 1.1 | 1.8 |
| Ozone layer depletion | kg CFC-11-eq | 2.3E-06 | 2.2E-06 | 2.7E-06 | 2.4E-06 | 1.2-07 | 3.3E-06 | 2.1E-06 | 3.6E-06 |
| Photochemical oxydation | kg $C_2H_4$-eq | 0.00311 | 0.00304 | 0.00355 | 0.00327 | 0.00025 | 0.00330 | 0.00212 | 0.00365 |
| Acidification | kg $SO_2$-eq | 0.012 | 0.012 | 0.014 | 0.013 | 0.001 | 0.014 | 0.009 | 0.015 |
| Eutrophication | kg $PO_4$-eq | 0.0043 | 0.0043 | 0.0048 | 0.00045 | 0.0002 | 0.0031 | 0.0020 | 0.0034 |
| Primary energy demand | MJ | 27 | 27 | 30 | 28 | 3 | 24 | 16 | 26 |

### 4.1 Effect of allocation method on results

The differences in results between products are partly the result of methodological issues, such as allocation method and system borders, and actual physical differences such as transport distances, numbers of processing steps, different packaging, etc. The differences caused by actual physical differences in the value chain and of different system borders are visible in the numbers for mass allocation. The differences in results between allocation methods are large. Using economic allocation, the differences between products are magnified, compared to mass allocation. Energy and hybrid allocation give results more close to those of mass allocation.

Economic allocation is sensitive to price changes in the market. This is demonstrated by the results in Table 4, which show a comparison in results between the base year (October 2006 to October 2007) and 2008. In 2008, the year of financial upheaval, previously high-priced products like loins, received a lower price. Similarly, the price of previously relatively high-priced fish species like cod decreased. This has several implications when using economic allocation. The decrease in cod prices decreased the impacts of all cod products. The decrease in loins prices combined with the relative stability of the prices of the other products caused a decrease in the impact of the loins product and an increase for the other product. These two effects add up for the loins product, giving a relatively large decrease in GWP (−16%), but they work in opposite directions for the other products, causing small increases in GWP (3–6%). The reason is that the share of the value of these in relation to loins increased. An especially interesting example is given by the eco-labelled wetpack. The environmental impact seems to have increased, but in reality, it is only the price that has increased. The other allocation methods gave, as expected, no difference in results between KRAV wetpack and regular wetpack.

Hybrid allocation gave results in between those for economic and mass allocation, but much closer to those of mass allocation. This is not surprising given the fact that the ratio between factors for products for human and animal consumption is only 2, whereas the price ratios are much higher, almost 100 for loins vs processing residue. The difference between mass and hybrid allocation is due to the processing stage since in the fishing stage hybrid allocation is identical to mass allocation because all species fished goes mainly to human consumption.

Allocation based on gross energy content gave a slightly higher impact of all cod products because cod has a higher-energy content than the average energy content of the entire

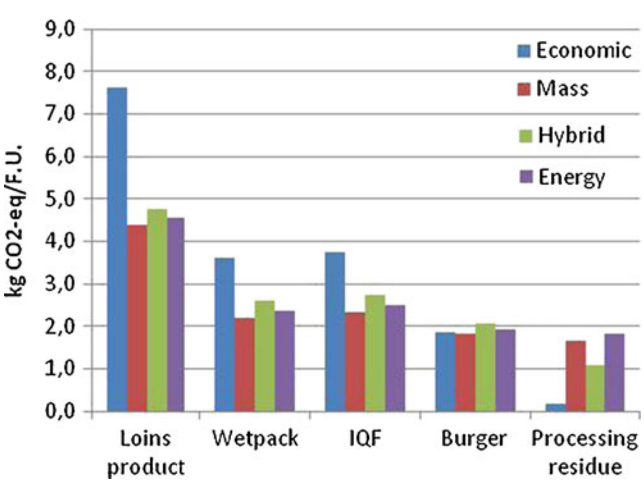


**Fig. 1** GWP of products using different allocation methods

**Table 4** GWP results for products from main processing outputs, economic allocation based on different market prices, using the 2007 catch rates and processing yields

| Product | 2007 Prices | 2008 Prices |
|---|---|---|
| Loins product | 7.6 | 6.4 |
| Wetpack | 3.6 | 3.8 |
| IQF | 3.7 | 3.9 |
| Burger | 1.8 | 1.7 |
| Processing residue | 0.16 | 0.15 |

Results are given in kg $CO_2$-eq/FU

**Table 5** GWP results with and without utilisation of fish guts and heads, economic and mass allocation

| | Economic, discarding guts and heads | Economic, using whole fish | Mass, discarding guts and heads | Mass, using whole fish |
|---|---|---|---|---|
| Loins product | 7.63 | 7.59 | 4.37 | 3.93 |
| Wetpack | 3.62 | 3.59 | 2.21 | 1.77 |
| IQF | 3.74 | 3.72 | 2.34 | 1.90 |
| Burger | 1.84 | 1.83 | 1.82 | 1.53 |
| Processing residue | 0.159 | 0.148 | 1.66 | 1.22 |

catch of the autoline fleet. Wolf-fish, redfish and halibut have much higher-energy content. Haddock, saithe, tusk and ling have a lower-energy content than cod but the difference is small, <15%.

### 4.2 Consequences of using different allocation methods considering the intended usage of the results

The results were intended to be used in internal improvement work (within the companies involved in the study and across the entire value chain) and documentation of environmental performance through communication to consumers, business customers and other interested parties.

#### *4.2.1 Use of information on environmental performance as a marketing tool*

An environmental benefit can be achieved if the market share of products with a low impact increases and/or if the average environmental impact of all products on the market is decreased. In order for this to happen, the information on the environmental performance of products must be readily available and the buyers must choose the products with less impact. The environmental performance of the studied products in relation to the average of seafood products on the market was in this case unknown because comparable numbers were not available. It seems likely that buyers would prefer products with less environmental impact, e.g. cod burgers over products with a high impact such as the loins product. This tendency would presumably be stronger when using economic allocation than when using mass allocation. The effect of hybrid allocation would give the same effect, but less than economic and more than mass allocation. The effect using energy allocation would probably be the same as using mass allocation. One complicating factor is that these products do not have the same perceived quality. The fact that the loins product has a much higher price in the market indicates that these products are valued higher by consumers, e.g. the perceived quality is higher. The products may also have different usage, i.e. they are prepared in different ways and used in different dishes. In the light of such considerations, it might be more appropriate to compare, e.g. the cod burger with a hamburger made from beef, rather than with cod wetpack.

The processing residue represents a rather different situation. Given the much higher impact for processing residue using mass than economic allocation of the buyer of this by-product, the producer of animal feed might be less inclined to use this raw material in the production when using mass allocation. However, for the seafood producer, it would be beneficial to use mass allocation since the impacts of all the other products are reduced. These products contribute more to the profits than the processing residue which more than anything else is a solution to reduce solid waste at the processing plant. The hybrid method allocates more impact to the products for human production than the processing residue, but the difference is much less than for economic allocation. In both of these cases, the use of energy allocation gives almost identical results to mass allocation.

In many cases, it is not only interesting to communicate the environmental performance of a product but the development in environmental performance, performance tracking. Buyers might be inclined to buy products for which a large reduction in environmental impacts has been achieved. When used for performance tracking, the economic allocation suffers a serious disadvantage. If prices are changed from the first to the second assessment, then the effects of actual improvement can be obscured or even seen as opposite. An increase in prices of a product can give an increase in impacts in spite of, e.g. a reduction in fuel consumption of the fishing vessel. This might be difficult to explain to the customers and might lead them to buy less of a product that has been improved. The other allocation methods do not have this disadvantage. Hybrid allocation can be viewed as a useful compromise, as it has the necessary stability over time to be used in performance tracking but to a certain degree reflects the differences in value and quality between products.

#### *4.2.2 Use of information on environmental performance for internal improvement work*

When used in internal improvement work, it is interesting to investigate whether the use of allocation method supports

different conclusions regarding the choice of improvement options. One possible improvement option is to bring cod entrails and heads ashore and using it for some purpose instead of discarding it into the sea, as is done today. The reason for the current practise is lack of freezer capacity onboard, but if sufficient incentives are in place it might be interesting for the vessel operators to build larger freezers. One such incentive is economical, but an improved environmental performance may also be a driving force. There are several possible usage areas for this material, e.g. production of biodiesel. Such utilisation would probably fetch a low price. If mass allocation had been used the effect would have been a significant decrease in impacts of the other products because the mass of this fraction is big, approximately 30 % of the whole fish. The effect on the other products using economic allocation would have been low. Hybrid allocation would have an intermediate effect but much closer to mass allocation than economic.

Another possible improvement option is using the processing residue for a purpose that is more highly valued by the market. The effect, using economic allocation is that the residue it will be allocated a higher environmental impact and the other products a lower impact. This could happen if the residue is used for, e.g., extraction of valuable biochemical components. A high price probably reflects a higher use of resources and higher emissions. It is thus likely that the higher price the residue fetches the higher environmental impact is avoided through avoiding the use of other products. In this way economic allocation is better than mass allocation because it gives a better indication of the avoided impacts taking place when the fish product is used for a certain purpose.

A third option is an increase of yield for human consumption in favour of animal feed. Such a change would not make a difference in the results for the other products using mass allocation but gives a decrease in impact using economic allocation. The use of mass allocation does not give incentive to increase the yield for human consumption. From these examples it seems that in certain cases, when using economic allocation, what makes sense in economical terms will also make sense in environmental terms, i.e. economic allocation better reflects the priorities of actors in the value chain. Hybrid allocation gives a similar effect as economic allocation. An increase in the proportion of fish being used for human consumption gives reductions in the impacts of the products for human consumption. One important difference is that set factors are used. The effect on the impact is not dependent on prices thus the instability connected with economic allocation is avoided. On the other hand this allocation method does not reflect avoided impacts caused by alternative products, in the same flexible way that economic allocation does.

## 5 Summary

The four main possibilities have their advantages and disadvantages. Mass allocation reflects only the underlying physical realities such a mass and energy streams and emissions to the environment, and as such, is potentially better understood by non-experts. It is not dependent on market fluctuations, and it is thus better suited for performance tracking. It gives an incentive for producers and fishermen to try to utilise waste materials, such as fish guts and processing residue. However, the use of this allocation method does not give an incentive for buyers to use this resource.

Economic allocation might be the preferred alternative in internal improvement work because there is a stronger link between environmental and economical performance than when using mass allocation. It will make it easier to sell waste materials because of the low environmental burden connected with such materials when prices are low. The burdens will increase when the price increases reflecting a higher value usage in which the consumption of products with a higher associated burden is avoided.

Economic allocation is not suitable for use in performance tracking, mainly because of the instability of prices. The effect of price differences might cloud real improvements in environmental performance or the opposite, a reduced environmental performance, in a certain time period. Prices do not only reflect increase in costs and hence increased resource use, but also other effects such as scarcity of resources and reduced income levels in the population.

When used in communication to the market, economic allocation might discourage buyers from buying high-quality products. The quality can be sensorial quality (e.g. loins product) or environmental quality (e.g. KRAV wetpack).

Hybrid allocation reflects, to a certain extent, the difference in prices in the market of products for human consumption, animal feed and incineration. However, the ratio of valuation between products for human and animal consumption is 2. This is much smaller than the value ratio of the studied products, which were a high as 100 between the loins product going to human consumption and the processing residue going to animal feed. Because the factors are fixed, this kind of allocation does not reflect market dynamics in the way economic allocation does. The method does not have the disadvantage of instability over time as economic allocation, but it also does not have the advantage of only reflecting underlying physical realities as mass allocation does. This allocation method is a compromise between mass and economic allocation without offering the same main advantages of these methods. Furthermore, the factors seem arbitrarily chosen. It is difficult to see how such factors should be calculated. What criteria should be behind such a calculation? Could

the same factors be used universally? Hybrid allocation is not recommended for any of the purposes suggested in this study.

Energy-based allocation is more linked to the underlying flows of energy and materials. Energy content could be an important parameter for those who raise animals and is certainly important if the purpose is incineration. It could also possibly be an important parameter for poor people who have to maximize energy intake based on their low income. For these people, the ratio of protein content to price might be more important. A large part of the fish products are sold to consumers in the developed world where obesity is an increasing problem. It is likely that the population do not want to maximize the energy content of their diet. Energy is not an important function for these people. The products in this study are sold in developed countries. Thus, the use of energy allocation is not recommended considering the intended usage of the results of this case study.

Based on these results and considerations, it is difficult to choose one preferred allocation method for all possible purposes. None of the allocation methods can be said to be objectively wrong but they could be more or less useful in supporting different kinds of decisions.

## 6 Recommendations

A standard method for calculating the environmental impact of seafood products should be developed to create a level playing field. For external communication purposes, the benefit of such a method could be that environmental performance would become a real competition factor on the market, encouraging the involved companies to reduce their impacts. This effect has already been seen in regard to ecolabels such as MSC regarding biological effects. Another beneficial effect could be to help the involved companies making the most optimal use of their resources towards reducing their environmental impact. Such a method should reflect the purpose of the study. For different purposes, different methodological choices might be appropriate. This includes the choice of allocation method.

## 7 Conclusions

This study has shown that the choice of allocation method is important for the results and for the potential consequences of using the results in different applications. The recommendation of ISO 14044 (2006) to avoid allocation through system expansion would be possible for one of the intended usage areas of the results for this case study. In the fishing stage, the use of a global functional unit (1 kg whole fish) is possible for internal improvement work. For the other intended purposes, it was necessary to use alternative 3 given in ISO 14044 (2006), which is allocation based on other relations between inputs and outputs, such as mass. These purposes were internal improvement work in the other parts of the value chain and communication of results on environmental performance of the products to the market.

Based on the results of one case study and considering the purposes of that study, it was not possible to arrive at one allocation method that would be the best choice in all situations. Of the studied methods, the preferred methods are mass and economic allocation. When used for performance tracking, mass allocation is preferred. In internal improvement work, economic allocation might be the better method because the conclusions of economical and environmental assessments would be more likely to point in the same direction. If the purpose is external communication to seafood buyers, e.g. consumers and businesses, mass allocation might be better understood. In some cases, mass allocation might however send the wrong signals to the market. This is the case when waste materials are sold for a low price for uses such as inclusion in animal feed or as raw material for biodiesel production.

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